Introduced Species as a Factor in Extinction and Endangerment of Native Fish Species

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Abstract- *In a previous analysis of extinctions of 40 North American native fishes, habitat alteration was cited as a factor in 29 cases (73%), introduced species in 27 cases (68%), and contaminants in 15 cases (38%). The present analysis of factors cited in Endangered Species Act (ESA) fish listings revealed a similar pattern. Of the 92 species listed through 1991, 69 final listing notices provided sufficient information about factors contributing to endangerment to allow analysis in a manner similar to the extinctions analysis. In these 69 cases, habitat degradation was again the most commonly cited factor (63 listings, 91%); contaminants were cited in 28 listings (41%); and introduced species were cited in 48 listings (70%)-in 40 (58%) as a factor in species decline and in 8 others (12%) as a continuing threat. Of these 48 listings, 35 introductions related to sportfishing (i.e., introduced as game, forage, or bait species). As with extinctions, most ESA listings cited more than one factor, and most cases in which introduced species were cited appeared to have been the consequence of intentional introductions. A recently completed study by the U.S. Congressional Office of Technology Assessment concluded that a pattern of intentional introductions of fish and other species causing harm as often as do unintentional introductions reflects "a history of poor species choices and complacency regarding their potential harm." These patterns suggest the need for greatly improved decision making in species introductions if we are to reduce threats to native fish fauna and avoid this impression of complacency.*

The U.S. Congressional Office of Technology Assessment (OTA) concluded that nonnative species “are here to stay and many of them are welcome" (OTA 1993). However, in the same document OTA concluded that other nonnative species "have had profound environmental consequences, exacting a significant toll on U.S. ecosystems." In reviewing the data for this paper, the validity of both of these seemingly contradictory statements was apparent. In presenting the results in various forums it has also been apparent that there is strong resistance, both by those who would introduce and those who generally oppose introductions, to accepting this validity.

The importance and value of nonnative species, at least in the United States, is exemplified by their extensive use in research, biological control, the aquarium industry, aquaculture, and fisheries management. While the benefits of using nonnative species are recognized, in this paper, I will focus on problems associated with fisheries management uses of nonnative species.

Nonnative species have become a component of current sportfishing programs in most states. The brown trout *Salmo trutta*, for example, is native to Europe and and western Asia but was introduced across the United States and is now a popular recreational species. Large recreational fisheries have developed for Pacific salmon *Oncorhynchus* spp. introduced into the Great Lakes, although it should be noted that hatchery production is used to maintain yields for these fisheries. Anglers who fish for rainbow trout *0. mykiss* in Virginia, Colorado, and Pennsylvania, and the millions of anglers who fish for largemouth bass *Microptenes salmoides* outside its native range (e.g., Oregon, California. and Arizona) clearly depend on a nonnative species for their angling enjoyment. The introduction of several nonnative species, for all their sportfishing value, has also been the source of substantial problems for native species. In testimony before the U.S. Congress, for example, OTA noted that biodiversity has declined both by the loss of native species and the addition of nonnative species.

Fisheries managers have facilitated the demand for and expectation that nonnative fishes will continue to be available for recreational fishing. However, we have done a less thorough job of anticipating or understanding the potential consequences of introductions (e.g., predation, competition, habitat alteration, hybridization, and disease transfer) and their outcomes for native species. There is a growing literature on the uses of introduced species and their effects on native species to which readers may turn for additional information (see Rosenthal 1980; Garman and Nielsen 1982; Courtenay and Stauffer 1984; Crossman 1991; DeVoe 1992; Rosenfield and Mann 1992). This paper provides an analysis of some of the most severe results of managing with nonnative fishes.

Methods

Miller et al. (1989) compiled information from a number of sources to provide a review of factors associated with the extinctions of 27 species and 13 subspecies of North American fishes over the past 100 years. They also generally assessed whether cited factors played a major role in the demise of each taxon. All analyses of extinctions in this paper are based on information presented by Miller et al. (1989).

Endangered Species Act (ESA; 16 U.S.C.A. §§1531 to 1544) listings (i.e., determinations of Threatened or Endangered status) are published in the Federal Register and are now required to include a description of factors that led to the listing. Information on factors cited in the listing of fish species under the ESA was derived from the files of the U.S. Fish and Wildlife Service for all fish listings through 1991. Many early listings provided only the name of the species with no specific information on the causes of decline or continuing threat and, therefore, were not included in my analysis. Adequate information existed for 69 of 92 U.S. species listed at the time of the analysis. Unfortunately, ESA listings did not consistently state the relative importance of the cited listing factors as Miller et al. (1989) did for extinctions.

Results

Extinctions

More than one factor was cited for most of the 40 extinct taxa analyzed by Miller et al. (1989). Habitat alteration was cited as a factor in 29 of 40 cases (73%), introduced species in 27 cases (68%), and contaminants in 15 cases (38%). Though the importance of factors other than introduced species is recognized and is presented here to clarify the relative frequency with which they have been cited by the reviewed sources, the remainder of this analysis is limited to introduced species effects.

Among the 27 cases in which introduced species were cited as a factor in extinction, over two-thirds (19 cases) were apparently the consequence of intentional introductions. Intentional introduction is used here to refer to purposefully bringing a species into an ecosystem, including containment facilities within them, to which that species is not native. The term intentional introduction therefore includes those taxa that are introduced directly (though not always legally) or indirectly into an aquatic habitat beyond their natural range through such actions as stocking game or forage species, or releasing bait or aquarium species. Species that have escaped from containment (e.g., aquacultural and aquarium production, rearing, or holding facilities) are thus also intentional introductions because escape from such facilities is a consequence of the initial introduction.

Introduced species were cited by Miller et al. (1989) as a "major" or "primary" factor in extinction of the native species in 10 of the 27 introduced species cases examined (37%). All 10 of these cases appear to have been the result of intentional introductions, with 7 of the 10 involving sportfishing introductions (i.e., introductions of game fish, forage for game fish, or bait species likely used in sportfishing). According to the information presented by Miller at al. (1989), habitat alteration was not cited as a factor in the extinctions of 6 of these 10 species. While I recognize that species decline in many cases is likely due to a combination of factors, Miller et al.'s (1989) findings indicate that habitat alteration is not, as is often suggested, always a necessary precursor to severe impacts by introduced species.

ESA Listings

The OTA (1993) noted that "biological communities can be radically and permanently altered without extinctions occurring." The first stated purpose of the ESA (Section 2(b)) is to provide a means of protecting the ecosystems upon which Threatened and Endangered species depend. There is perhaps no clearer signal, short of extinction, of the disruption of ecosystem integrity than the listing of one of its component species under the ESA.

In the 69 fish listings analyzed (Table 1), habitat alteration was the most commonly cited factor (63 species, 91%). Contaminants were cited in-28 species listings (41%), and introduced species were cited in 48 cases (70%)-in 40 (58%) as a factor in the decline of and in 8 others (12%) as a continuing threat to native species. Often several introduced species were cited and most ESA listings cited more than one factor. As with extinctions, most cases that cited introduced species appeared to have been the consequence of intentional introductions.

Among the 48 cases that cited introduced species as a listing factor, 7 involved ornamental species, 7 involved aquacultural species (other than ornamentals), and 6 related to pest control. Of the 48 cases, 35 involved sportfishing introductions; centrarchids were the most frequently cited taxon of sport fish.

The largemouth bass was the most frequently cited individual species (21 cases). Green sunfish *Lepomis cyanellus* was cited in nine cases. Other centrarchids included bluegill *L. macrochinis*, crappie *Pomoxis* spp., smallmouth bass *Microptents dolomieu*, and other sunfish. Ictalurids were also commonly cited: channel catfish *Ictalurus punctatus* was cited in 7 cases and a variety of bullhead species *Ameiurus* spp. were cited in 11 cases. Cited baitfish species included red shiner *Cyprinella lutrensis* and the fathead minnow *Pimephales promelas* and "other baitfish." Rainbow trout and brown trout were cited in seven and 31% cases, respectively, primarily for having caused problems through hybridization with native trout species or as predators of smaller species. In most cases, the listing information did not indicate whether the introduction was sanctioned by a public agency.

Discussion

Primack (1993) pointed out that whereas patterns of evolution have proceeded largely as a result of geographic isolation, "humans have radically altered this pattern by transporting species throughout the world." Any introduced species that survives the transfer necessarily affects the receiving ecosystem. In a recent text on biological pollution, Courtenav (1993) summarized that "every introduction will result in impacts to native biota, which may range from almost nil to major, including extinction, with time." Nonnative species can affect native species through a number of mechanisms including hybridization, competition, predation, pathogen transfer, and habitat alteration.

As noted earlier in this paper, prior habitat degradation is not a necessary precursor to severe impacts from introduced species. However, habitat degradation clearly can make a species and its supporting ecosystem more vulnerable to the effects of a nonnative species. This is apparently the case in the Colorado River where the combination of dams and introduced species has led to the endangerment of four native fish species adapted to large, flowing river systems (Minckley 1991). Moyle and Williams (1990) determined that large water projects, in concert with introductions of fish species better able to cope in altered habitats, were largely responsible for the decline of California's native fish fauna. In particular, the presence of introduced species was a “very important factor" or "principal factor" (Moyle and Williams 1990) in the status of 49% of species described as extinct, endangered, or in need of special protection.

Whether habitat has been altered or not, the decision to introduce must be made with great care. Unfortunately, the results of a recent investigation of a group of aquatic taxa (OTA 1993) suggests this may not have always been the case. Whereas the view is often expressed that unintentional introductions constitute the major source of problems to natural ecosystems, OTA (1993) found that intentional introductions, even using a narrower interpretation of intentional (*viz*, deliberate releases) than is used in this paper, are as likely to cause problems as are unintentional introductions. The OTA concluded that this pattern reflects "a history of poor species choices and complacency regarding their potential harm." Whereas the results of this analysis may support OTA's conclusion about fisheries management choices, I am less convinced that the source of our mistakes is complacency.

I suggest that the record of "poor species choices" is one of false assumptions and unrealistic expectations. For example, in situations where human activity has so altered ecosystems that native species have been lost or severely reduced, nonnative species or specific different life stages of native species have been used in efforts to restore some perceived ecosystem function. When an altered environment cannot support a particular life stage of a native species, culture techniques may serve a useful purpose in bridging the gap until the native species is again able to persist on its own. An example of this type is the reintroduction of cordgrass *Spartina alterniflora* for shoreline stabilization along the U.S. Atlantic coast. However, this same species was then used outside its native range and is now the source of increasingly severe problems in the Pacific Northwest. Though the same introduction decision was made, the outcome when the species was used outside its native range was very different.

Table 1. Analysis of factors cited in listing of fish species under the Endangered Species Act.[a] Names follow Robins et al. (1991).

		Listing factor(s)			Purpose of introduction			
Common name	Scientific name	Habitat alteration	Pollution	Introduced species	Sportfishing	Pest control	Ornamental	Aquaculture
Catfish, Yaqui	Ictalunts pricei	X		X	X			
Cavefish, Alabama	Speoplatvrhinus poulsoni		X					
Cavefish, Ozark	Amblvopsis rosae		X					
Chub, bonytail	Gila elegans	X		X	X			X
Chub, Borax Lake	Gila boraxobius	X		X[b]				
Chub, Chihuahua	Gila ingrescens	X	X	X	X	X		
Chub, humpback	Gila cypha	X		X	X			X
Chub, Hutton tui	Gila bicolor spp,	X	X[b]	X[b]				
Chub, Owens tui	Gila bicolor snvderi	X		X	X			
Chub, slender	Erimvstax cahni	X	X					
Chub. Sonora	Gila ditaenia			X	X			
Chub, spotfin	Cyprinella monacha	X	X					
Chub, Virgin River	Gila robusta semidnuda	X		X	X			
Chub, Yaqui	Gila purpurea	X		X	X			
Dace, Ash Meadows speckled	Rhinichthvs osculus nevadensis	X		X	X	X		
Dace, blackside	Phoxinus cumberlandensis	X		X	X			
Dace, Clover Valley speckled	Rhinichthys osculus oligoporous	X		X	X			
Dace, desert	Eremichrhvs acros	X		X[b]				
Dace, Foskett speckled	Rhinichthvs osculus spp.	X		X[b]				
Dace, Independence Valley speckled	Rhinichtirvy osculus lethopoms	X		X	X			
Dace, Moapa	Moapa coriacea	X		X			X	
Darter, amber	Percina antesella	X	X	X[b]				
Darter, bayou	Etheostoma rubrum	X	X					
Darter, Elk River	Etheostoma wapiti	X						
Darter, goldline	Percina aurolineata	X	X					
Darter, leopard	Percina pantheria	X	X					
Darter, Niangua	Etheostoma nianpae	X		X	X			
Darter, slackwater	Etheostoma boschungi	X						
Darter, snail	Percina tanasi	X						
Logperch, Conasauga	Percina jenkinsi	X	X	X[b]				
Loaperch, Roanoke	Percinu rex	X	X					
Madtom, Neosho	Noturus placidus	X	X					
Madtom, Scioto	Nottinis traurmani	X						
Madtom, Smokev	Notunis baileyi	X	X					
Madtom, vellowfin	Notunts flavipinnis	X	X					
Minnow, loach	Rhinichthys cobitis	X		X	X			
Pupfish, Ash Meadows Amargosa	Cyprinodon nevadensis mionectes	X		X	X	X	X	
Pupfish, desert	Cyprinodon macularius	X	X	X	X		X	X
Pupfish, Devils Hole	Cyprinodon diabolis	X						
Pupfish, Leon Springs	Cvprinodon bovinus	X		X	unclear			
Sculpin, pygmy	Cottus pygmaeus	X	X					
Shiner, beautiful	Cvprinella formosa	X		X	X			
Shiner, blue	Cyprinella caerulea	X	X					
Shiner, Cahaba	Notropis cahabae		X					
Shiner, Cape Fear	Notropis mekistocholas	X	X					
Shiner, Pecos bluntnose	Notropis simus pecosensis	X	X	X	unclear			
Silverside, Waccarnaw	Menidia extensa		X	x[b]	x[b]			
Spikedace	Meda fulgida	X		X	X			
Spinedace. Big Spring	Lepidorneda mollispinis pratensis	X		X		X		
Spinedace, Little Colorado	Lepidomeda vittata	X	X	X	X			
Spinedace, White River	Lepidomeda albivallis	X	X	X		X	X	
Springfish, Hiko White River	Crenichthys baileyi grandis	X		X	X		X	

Table 1 (continued).

Common name	Scientific name	Listing factor(s) Habitat alteration	Pollution	Introduced species	Purpose of introduction Sportfishing	Pest control	Ornamental	Aquaculture
Springfish, Railroad Valley	Crenichthys nevadae	X		X			X	X
Springfish, White River	Crenichthys baileyi	X		X	X		X	
Squawfish, Colorado	Ptvchocheilus lucius	X		X	X			
Sturgeon, pallid	Scaphirhynchus albus	X		X[b]				X[b]
Sturgeon, Gulf	Acipenser oxyrhynchus desotoi	X	X					
Sucker, June	Chasmistes lioris	X	X	X	X			X
Sucker, Lost River	Deltistes luxatus	X	X	X	X			
Sucker. Modoc	Catostomus microps	X		X	X			
Sucker, razorback	Xyraucheri texanus	X		X	X			X
Sucker, shortnose	Chasmistes brevirostris	X	X	X	X			
Sucker, Warner	Catostornus warnerensis	X		X	X			
Topminnow, Gila	Poeciliopsis occidentalis	X		X	X	X		
Trout, Apache	Oncorynchus apache	X		X	X			
Trout, greenback cutthroat	Oncorynchus clarki stomias	X			X			
Trout, Lahontan cutthroat	Oncorynchus clarki henshawi	X			X			
Trout, Little Kern golden	Oncorhynchus aguabonita whitei	X		X	X			
Trout, Paiute cutthroat	Oncorynchus clarki seleniris	X		X	X			

[a] Analysis limited to those species for which information in Fish and Wildlife Service ESA final rule file included the five ESA listing factors.
[b] Cited as continuing threat rather than cause of decline.

Use of nonnative species to maintain ecosystem function must rely on solid understanding and realistic expectations. To some extent, expectation and prediction can be improved by gathering information on both the species being considered for introduction and the receiving environment. However, I believe OTA (1993) identified a particularly important basis for false assumptions when it singled out fisheries managers for continuing to use the "erroneous concept" of the vacant niche (i.e., "filling" a perceived void in an ecosystem with an introduced species).

For example, the waters behind a new dam may concentrate detritus and silt-dwelling invertebrates where a previously abundant stream-dwelling native salmonid now survives only in low numbers. The ecosystem continues to function in some manner; we simply don't care for what the altered energy and nutrient use pattern is now producing as a result of the manipulation. Because we do not see the outputs of the altered system as anything of immediate use, some refer to the new pattern as having "voids."

In many past cases, species chosen to "fill the void" appear to have been selected without considering potential effects on the receiving ecosystem because those species were deemed to be of more immediate benefit to humans than what persisted of the native community in the altered ecosystem. Perhaps it was seen as simpler to look for ways to channel the altered resource use pattern into a product of more immediate human benefit than to address alternatives to the proposed manipulation seriously or even to look for ways to minimize its consequences. Often the choice has been instead to manipulate the system further by introducing new species to fill these illusory empty niches.

In the waters behind the new dam cited above, one biologist may see just a single "empty niche" and introduce carp to convert the detritus and invertebrate biomass into fish flesh, Another biologist (or creative but misguided angler) may imagine any number of "empty niches" to fill and decide, for example, to introduce a crayfish and a small catostomid to feed on the detritus now concentrated in that portion of the watershed, plus maybe a small centrarchid to prey on the newly abundant benthic invertebrates. Then a large predatory centrarchid or two may be introduced to feed on this prey base and create a new fishery. Some refer to this approach of filling imaginary empty niches by introducing a whole suite of species as "ecosystem management," though most often it involves only a portion of the ecosystem. I believe it is more akin to ecosystem recreation, with all of the attendant evolutionary ramifications for native species throughout that and any interconnected ecosystems. Because of the uncertainties of predicting a particular result in such cases, OTA appropriately warns that "application of this approach to natural communities is inappropriate."

One other issue that must be addressed to understand the record on introductions, one that clearly links introductions to activities that alter habitats, is that introductions have often been driven by required mitigation for federal activities (e.g., dams), The species chosen to meet mitigation demands could have been native but often has been a nonnative species. Often nonnative species are the simplest alternative because culture techniques for a few commonly used species are well understood. Because of their prior use in other environments, these commonly used nonnatives are also species the public has become accustomed to seeing portrayed as the preferred species.

Conclusions

Nonnative aquatic species have been and continue to be both a source of economic benefits and costs to many sectors of society and a major factor in the loss of biological diversity. Despite this importance, the implications of nonnative species introductions have in general been underrecognized. This may be changing.

Recent headlines have included such items as the following: “Exotic Plants, Animals Imperil U.S. Ecosystems" (Los Angeles Times); "Court Action is Studied to Shut CAP" (ArLona Republic, 21 January 1994-referring to the potential for nonnative species transported by the Central Arizona Project, to harm native species); "Biology That's Alien and Expensive" (Washington Post, 7 October 1993); and "Introduction of Nonnative Fish is Devastating Many Local Rivers and Lakes" (Oregonian, 28 November 1990). The articles have not projected positive images of fisheries management decisions, but I believe the increasing awareness of this issue within and outside the fisheries profession suggests the need to improve upon our record.

Though calls by Congress for further research have been used as a delaying or obstructionist tactic, additional research can help clarify the risks of nonnative species introductions, prioritize actions intended to minimize such risks, and enable and promote the use of native species. However, I believe the greatest need is a change in attitude from one dominated by value judgements based on immediate human benefit to one that values the integrity of native ecosystems and all of its component species, a huge long-term benefit to our children's children, indeed to the human species. Soule (1986) warned that "dithering and endangering are often linked;" let us not dither any longer.

Acknowledgments

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